Chapter 3. Microbiology

INTRODUCTION

The City of San Diego performs shoreline and water column bacterial monitoring in the region surrounding the South Bay Ocean Outfall (SBOO). This is designed to assess general water quality conditions, evaluate patterns in movement and dispersal of the wastewater plume, and monitor compliance with the 2001 California Ocean Plan according to NPDES permit specifications (see Chapter 1). The final results of bacteriological and individual station compliance data are submitted to the International Boundary and Water Commission and San Diego Regional Water Quality Control Board in the form of monthly receiving waters monitoring reports. Bacteriological densities, together with oceanographic data (see Chapter 2), are evaluated to provide information about the movement and dispersion of wastewater discharged through the outfall. Analyses of these data may also help identify point or non-point sources other than the outfall as contributing to bacterial contamination events in the region. This chapter summarizes and interprets patterns in bacterial concentrations collected for the South Bay region during 2006.

MATERIALS AND METHODS

Field Sampling

Water samples for bacteriological analyses were collected at fixed shore and offshore sampling sites during 2006 (**Figure 3.1**). Sampling was performed weekly at 11 shore stations to monitor bacterial levels along public beaches. Three shore stations (S0, S2, S3) located south of the US/Mexico border are not subject to California Ocean Plan (COP) water contact standards. Eight other shore stations (S4–S6, S8–S12) located between the border and Coronado are subject to the COP standards (see **Box 3.1**). In addition, 28 offshore stations were sampled monthly, usually over a 3-day period. These 28 offshore sites are located in a grid surrounding the outfall along the 9, 19, 28, 38, and 55-m depth contours. Three of these stations (I25, I26, I39) are considered kelp bed stations and are subject to the COP water contact standards. The kelp stations were sampled for bacterial analysis 5 times each month, such that each day of the week is represented over a 2-month period. The 3 kelp stations were selected because of their proximity to suitable substrates for the Imperial Beach kelp bed; however, this kelp bed is transient with variable size and density (North 1991, North et al. 1993). Thus, these 3 stations are located in an area where kelp is only occasionally found.

Seawater samples from the 11 shore stations were collected from the surf zone in sterile 250-mL bottles. In addition, visual observations of water color and clarity, surf height, human or animal activity, and weather conditions were recorded at the time of collection. The samples were then

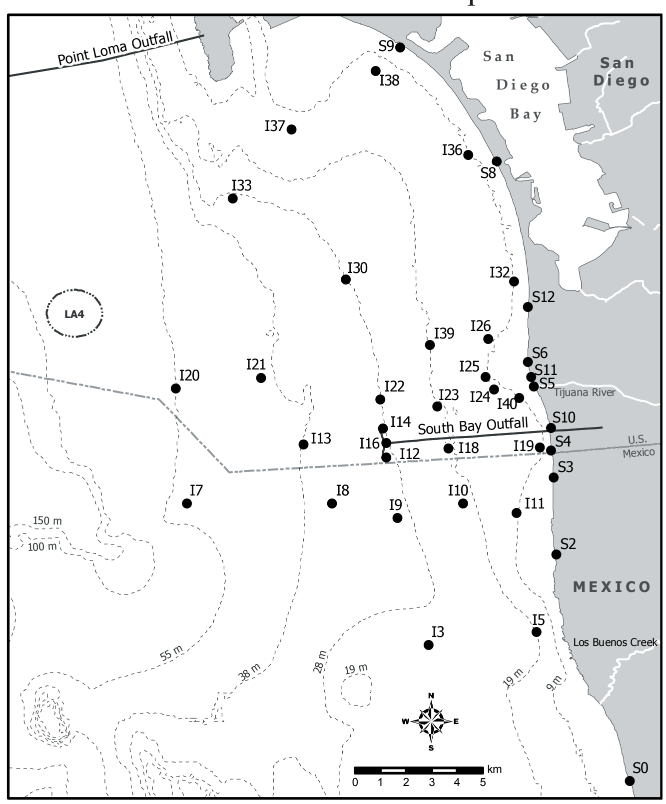


Figure 3.1
Water quality monitoring stations where bacteriological samples were collected, South Bay Ocean Outfall Monitoring Program.

Box 3.1

Bacteriological compliance standards for water contact areas, 2001 California Ocean Plan (SWRCB 2001). CFU = colony forming units.

(1) *30-day total coliform standard* — no more than 20% of the samples at a given station in any 30-day period may exceed a concentration of 1000 CFU per 100 mL.

(2) *10,000 total coliform standard* — no single sample, when verified by a repeat sample collected within 48 hrs, may exceed a concentration of 10,000 CFU per 100 mL.

(3) *60-day fecal coliform standard* — no more than 10% of the samples at a given station in any 60-day period may exceed a concentration of 400 CFU per 100 mL.

(4) *geometric mean* — the geometric mean of the fecal coliform concentration at any given station in any 30-day period may not exceed 200 CFU per 100 mL, based on no fewer than 5 samples.

transported on blue ice to the City's Marine Microbiology Laboratory and analyzed to determine concentrations of total coliform, fecal coliform, and enterococcus bacteria.

Seawater samples were collected at 3 discrete depths at each of the offshore sites and analyzed for total coliform, fecal coliform, and enterococcus bacteria, as well as total suspended solids and oil and grease during the monthly sampling. These samples were collected using either a series of Van Dorn bottles or a rosette sampler fitted with Niskin bottles. Aliquots for each analysis were drawn into appropriate sample containers. The bacteriological samples were refrigerated on board ship and then transported to the City's Marine Microbiology Laboratory for analyses. The total suspended solids and oil and grease samples were taken to the City's Wastewater Chemistry Laboratory for analyses. Visual observations of weather, sea state, and human or animal activity in the area were also recorded at the time of sampling. Monitoring of the SBOO area and neighboring coastline also included aerial and satellite image analysis performed by Ocean Imaging Corporation (see Chapter 2).

Laboratory Analyses and Data Treatment

All bacterial analyses were performed within 8 hours of sample collection and conformed to standard membrane filtration techniques (see APHA 1992). The Marine Microbiology Laboratory follows guidelines issued by the EPA Water Quality Office, Water Hygiene Division and the California State Department of Health Services (CDHS) Environmental Laboratory Accreditation Program with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1992).

Colony counting, calculation of results, data verification and reporting all follow guidelines established by the EPA (see Bordner et al. 1978) and APHA (1992). According to these guidelines, plates with bacterial counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values during the calculation of compliance with COP standards and mean values.

Quality assurance tests were performed routinely on water samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split field samples were collected and processed according to method requirements to measure intra-sample and inter-analyst variability, respectively. Results of these procedures were reported in the Laboratory's Quality Assurance Report (City of San Diego 2007).

Shore and kelp bed station compliance with COP bacteriological standards were summarized according to the number of days that each station was out of compliance (see Box 3.1). Bacteriological data for offshore stations are not subject to COP standards, but were used to examine spatio-temporal patterns in the dispersion of the waste field. Spatial and temporal patterns in bacteriological contamination were determined from mean densities of total coliform, fecal coliform, and enterococcus bacteria. Mean densities (±standard error) were calculated by month, station, depth, and time period (pre-discharge and post-discharge); compliance resamples were not considered for these calculations. Bacteriological, oil and grease and suspended solid data were log(x+1) transformed to improve conformity to normality for use in parametric statistical analyses. Normality was determined graphically and homogeneity of variances was tested using the F-test. Monthly rainfall and oceanographic conditions (see Chapter 2), as well as other events (e.g., stormwater flows and turbidity plumes, nearshore and surface water circulation patterns) identified through remote sensing data were evaluated relative to the bacterial data.

COP and AB 411 (CDHS 2000) bacteriological benchmarks were used as reference points to distinguish elevated bacteriological values in receiving water samples discussed in this report. These were >1000 CFU/100 mL for total coliforms, >400 CFU/100 mL for fecal coliforms, and >104 CFU/100 mL for enterococcus bacteria. Furthermore, contaminated water samples were identified as samples containing total coliform concentrations ≥1000 CFU/mL and a fecal:total (F:T) ratio ≥0.1 (see CDHS 2000). Samples from offshore monthly water quality stations that met these criteria were used as indicators of the SBOO waste field, while those with total coliform concentrations ≥1000 CFU/mL and a fecal:total (F:T) ratio <0.1 were identified as stormwater discharge from the Tijuana River and San Diego Bay.

RESULTS AND DISCUSSION

Bacteriological densities in 2006 were generally high in the South Bay region, despite a relatively small amount of rainfall over the year. For example, annual mean concentrations of fecal coliform bacteria along the shoreline near the Tijuana River (stations S5, S6, S11) were similar to levels seen during 2005, a year with much heavier rainfall (**Figure 3.2**). Overall, 10% of the samples (n=201) analyzed in 2006 had total coliform concentrations greater than or equal to the 1000 CFU/100 mL benchmark. Of these high values, 111 were collected at shore sites, 9 were collected during the kelp station surveys, and 81 were collected during the monthly offshore surveys. Thirty-eight of these monthly offshore samples and one of the kelp survey samples had F:T ratios ≥0.1, which are indicative of contaminated water (n=39). These samples were further evaluated to assess possible patterns in plume movement (see below).

Temporal Variability

February through May, October, and December were the wettest months of the year and had the highest densities of indicator bacteria in shoreline samples (**Table 3.1**). Twenty-two of the 24 samples with total coliform concentrations that exceeded the 10,000 CFU/100 mL standard occurred during these wet months, with the 2 other exceedances occurring in January. Although January was not a wet month, the January exceedances correspond to a 4-day period (January 1–4) when all of the rainfall for the month occurred. The Tijuana River was flowing at 16.2±5.6 million gallons/day (mean±SE) during this period (IBWC, unpublished data).

Fecal coliform concentrations along the shoreline also corresponded to the pattern of rainfall in 2006 (**Figure 3.3A**), and were significantly correlated with monthly rainfall (Spearman correlation; n=12, p=0.006). This pattern has also been observed since 1995 when shoreline sampling began (Figure 3.3B) and the relationship between fecal coliform concentrations and annual rainfall was significant (Spearman correlation; n=12, p=0.001). However, deviations from this trend occurred on 2 occasions in 2006: (1) relatively low densities of fecal coliforms were detected in March despite fairly heavy rainfall; and (2) in July, high densities of fecal coliforms occurred with little rainfall. The

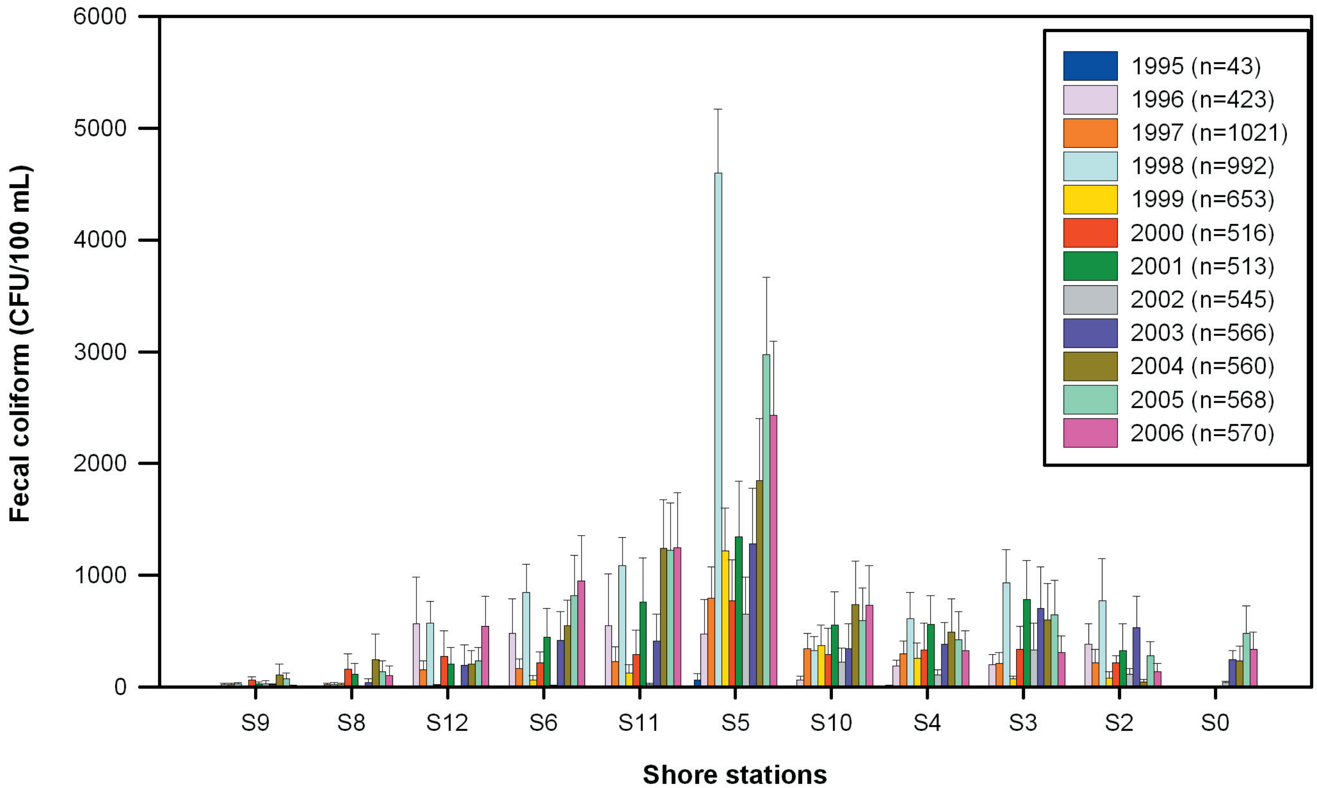


Figure 3.2
Mean annual fecal coliform densities (mean±SE) for each SBOO shore station from 1995–2006. Stations are arranged from north to south on the x-axis. Stations S5, S6, and S11 are all within 1 km of the Tijuana River. Sampling for stations S10–S12 started in October 1996 and sampling for station S0 started in August 2002.

elevated bacterial densities in July were collected at shore stations S5, S6, S8, S11, and S12 on July 18 and may have been caused by a sewage spill from Mexico that flowed into the Tijuana River around July 15. After the sewage spill, the Tijuana River had a mean flow of 10.5±8.4 million gallons/day from July 16–17.

Samples with high densities of indicator bacteria were collected from the kelp stations during most months of 2006. However, as with the shore stations, most of the kelp station samples (71%) with total coliform concentrations ≥1000 CFU/100 mL were collected during February through May, October, and December (**Appendix B.1, B.2**). Three of these samples had F:T ratios ≥0.1, but the fecal coliform densities were low and the samples were probably not indicative of contaminated wastewater from the SBOO.

Monthly sampling of indicator bacteria at the other offshore sites also showed distinct seasonal trends related to rainfall and storm discharge (**Figure 3.4**). Two-thirds of the 81 samples with total coliform concentrations ≥1000 CFU/100 mL occurred during February through May, October, and December (**Appendices B.2, B.3**). Additionally, 13 of the 17 samples collected at the stations along the 9 and 19-m contours that were representative of contaminated water occurred during those months. Most, if not all, of these inshore samples were likely related to discharge from the Tijuana River and Los Buenos Creek. During periods of northward current flows, discharge from the Tijuana River and Los Buenos Creek is carried up the coast towards Imperial Beach and may affect water quality at inshore stations (Largier et al. 2004, Ocean Imaging 2005, City of San Diego 2006).

Water column stratification was seasonal and this was apparent in the offshore monthly water quality samples. The wastewater plume remained sub-surface most of the year, but was detected in surface waters at stations along the 28-m contour

Table 3.1

Shore station bacterial densities and rainfall data for the SBOO region during 2006. Mean total coliform, fecal coliform, and enterococcus bacteria densities are expressed as CFU/100 mL. Rain is measured at Lindbergh Field, San Diego, CA. Sample size (n) for each station is given parenthetically and excludes resamples. Stations are listed north to south in order from left to right.

Month	Rain (in.)		S9 (52)	S8 (52)	S12 (52)	S6 (52)	S11 (52)	S5 (52)	S10 (51)	S4 (51)	S3 (52)	S2 (52)	S0 (52)
Jan	0.36	*Total*	22	842	771	42	194	241	3250	3272	3284	244	6480
		Fecal	8	26	24	12	7	81	54	54	608	76	236
		Entero	3	42	34	25	10	141	94	105	528	59	143
Feb	1.11	*Total*	37	7	1553	4853	6102	8009	15	30	4459	8004	1315
		Fecal	7	2	183	1197	3087	6003	3	2	1661	1151	119
		Entero	9	4	212	72	1696	3156	2	3	2760	412	49
Mar	1.36	*Total*	909	8	4490	4780	6200	13300	8525	6400	3725	4768	525
		Fecal	36	4	417	467	216	6265	852	337	126	281	20
		Entero	53	2	15	88	40	6043	151	83	68	211	11
Apr	0.88	*Total*	16	7	4061	4770	7012	6950	6062	8033	4710	225	111
		Fecal	2	7	709	2520	3075	3110	1317	1553	711	10	21
		Entero	3	2	8	188	248	3029	30	31	15	9	8
May	0.77	*Total*	43	65	3216	3241	6611	9764	2746	201	137	745	2984
		Fecal	2	5	2004	1646	3013	7210	746	12	11	13	135
		Entero	4	8	76	75	244	5299	12	10	10	22	32
Jun	0.00	*Total*	140	65	140	225	135	110	42	43	90	201	555
		Fecal	44	7	14	19	14	14	4	7	10	73	82
		Entero	39	4	4	12	10	21	2	9	14	25	17
Jul	0.04	*Total*	200	4105	1810	4105	4015	4065	312	782	1829	1261	847
		Fecal	28	1207	793	3026	3006	3010	32	138	163	94	237
		Entero	5	9	13	25	11	29	8	16	19	23	11
Aug	0.01	*Total*	16	13	68	16	10	13	16	32	162	10	4244
		Fecal	3	2	55	2	2	6	4	25	155	3	169
		Entero	2	2	142	2	2	3	2	13	42	2	34
Sep	0.00	*Total*	75	17	20	16	16	11	16	17	11	359	1354
		Fecal	5	3	9	3	3	3	3	7	4	9	99
		Entero	5	2	3	3	2	4	2	2	4	2	28
Oct	0.76	*Total*	28	18	3217	3212	3207	3210	3205	81	92	61	3384
		Fecal	7	3	1886	2403	2403	882	3003	40	26	17	139
		Entero	4	4	75	683	126	24	110	6	5	10	98
Nov	0.15	*Total*	11	26	22	98	11	13	12	22	13	57	7010
		Fecal	9	2	3	62	2	4	2	3	4	5	1437
		Entero	7	2	5	15	2	6	8	5	11	6	443
Dec	0.71	*Total*	14	40	21	29	40	4167	5528	5470	6305	1407	5038
		Fecal	7	42	9	6	8	3008	2361	1952	376	39	1521
		Entero	2	22	7	13	7	3253	41	41	38	34	127
Annual means													
		Total	**118**	**419**	**1631**	**2078**	**2774**	**4089**	**2512**	**1982**	**1980**	**1354**	**2932**
		Fecal	**12**	**101**	**546**	**952**	**1245**	**2434**	**732**	**326**	**312**	**138**	**337**
		Entero	**11**	**9**	**52**	**107**	**192**	**1721**	**40**	**28**	**281**	**64**	**83**

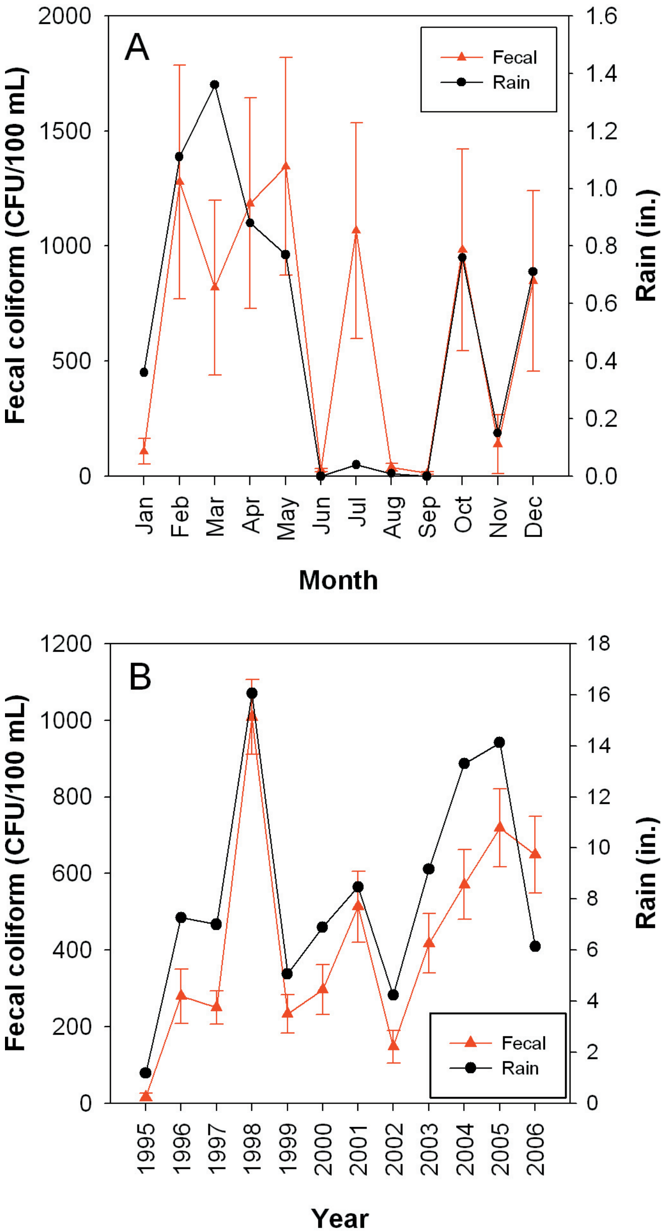


Figure 3.3
Mean fecal concentrations (mean±SE) at shore stations vs. rain by (A) month in 2006 and (B) year. See Figure 3.2 for sample sizes. Shoreline sampling began in October 1995. Rain for 1995 includes only October–December. Rain was measured at Lindbergh Field, San Diego, CA.

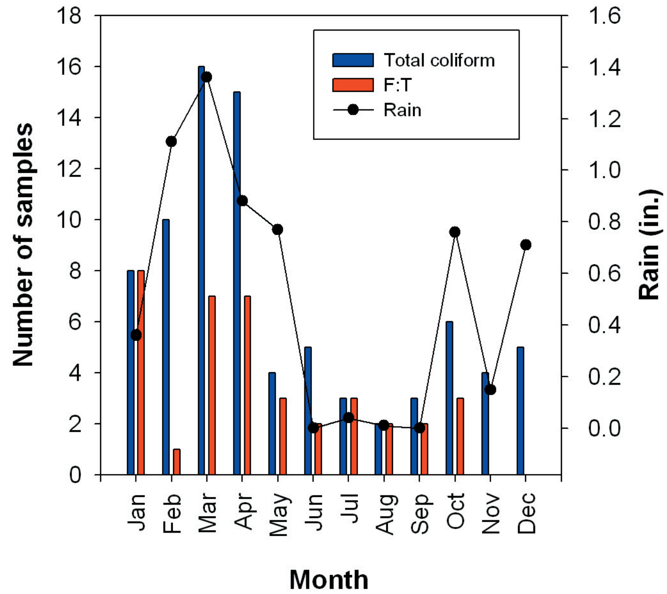


Figure 3.4
SBOO monthly offshore water quality samples with high bacterial densities collected in 2006. Total coliform=number of samples with total coliform densities ≥1000 CFU/100 mL; F:T=number of samples with total coliform densities ≥1000 CFU/100 mL and fecal to total coliform ratio (F:T)≥0.1. Rain was measured at Lindbergh Field, San Diego, CA.

in January (**Figure 3.5**; Appendix B.2). Seasonal stratification did not begin to develop until March/April (see Chapter 2).

Spatial Variability

Elevated bacterial densities along the shoreline and in shallow, nearshore waters appeared to be related to sources other than the SBOO. Proximity to the Tijuana River and Los Buenos Creek discharges appeared to have greater influence on bacteriological levels along the shoreline. For example, the highest densities of indicator bacteria occurred along the shore at the 6 stations closest to the Tijuana River (i.e., S4–S6, S10–S12) and station S0 located south of Los Buenos Creek in Mexico (Table 3.1). Station S5, located adjacent to the mouth of the Tijuana River, had the highest mean bacterial levels of all of the shore stations sampled in 2006. Station S0, the southernmost shore station, was likely impacted by discharge from the nearby Los Buenos Creek and/or southerly alongshore flow carrying Tijuana River discharge. Contaminants from upstream sources (e.g., sod farms and runoff not captured by the canyon collector system) and the Tijuana estuary (e.g., decaying plant material) are released during increased river flow and extreme tidal exchanges and are a likely bacterial source for the stations closest to the Tijuana River (Largier et al. 2004). The San Antonio de los Buenos Wastewater Treatment Plant, Mexico releases its partially treated effluent

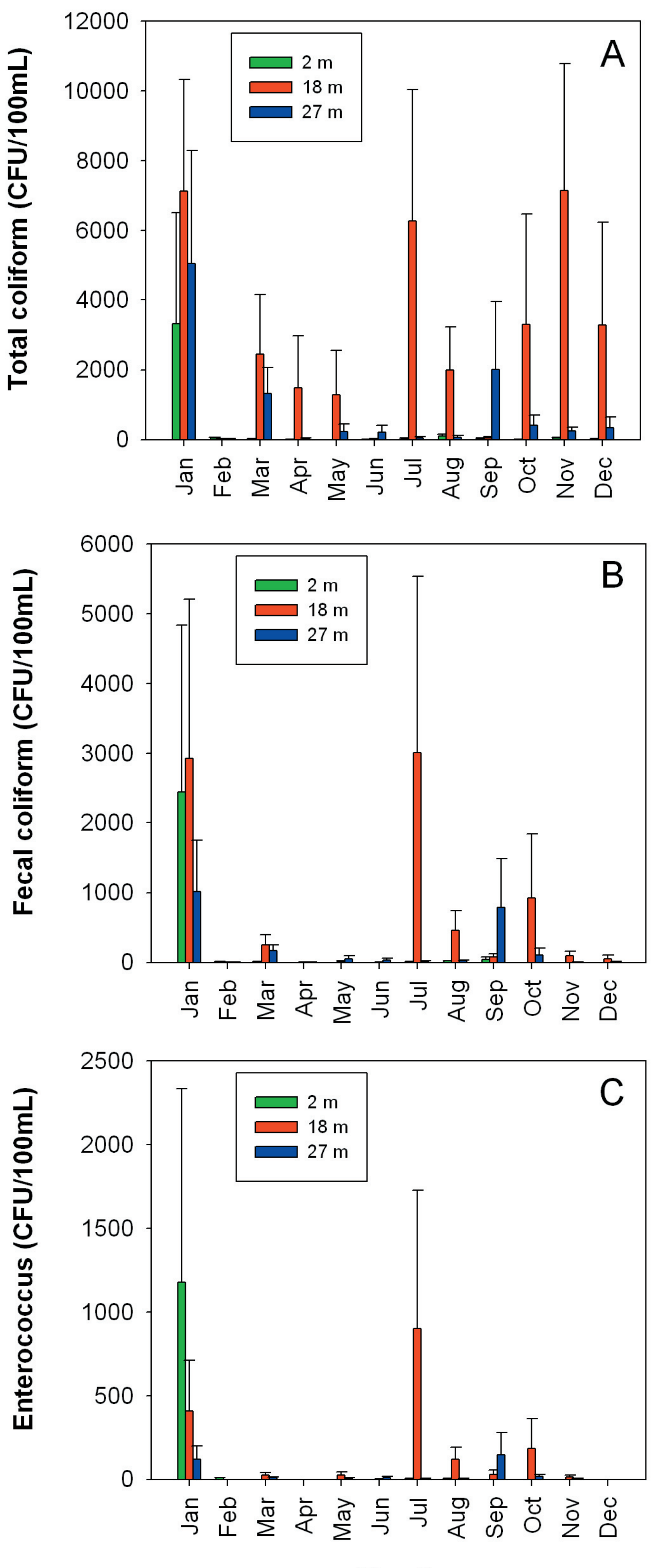


Figure 3.5
Bacterial concentrations at monthly offshore SBOO stations (I9, I12, I14, I16, I22) along the 28-m contour for surface (2 m), mid-depth (18 m), and bottom waters (27 m) during 2006: (A) total coliform, (B) fecal coliform, and (C) enterococcus bacteria. Values are means±SE; n=5.

through Los Buenos Creek and this flow may have affected total and fecal coliform levels both south and north of the international border.

Discharge from the Tijuana River also affected water quality at various stations along the 9 and 19-m contours (Ocean Imaging 2006 a, b, c). Stormwater discharge from the Tijuana River from February through May, and during October and December was likely responsible for elevated bacterial densities at these nearshore stations. For example, there were 28 monthly offshore water samples from these stations representative of stormwater (i.e., total coliforms ≥1000 CFU/100 mL and F:T ratios <0.1) taken during these months (Appendix B.3). Except for those samples collected from stations nearest the outfall (I12, I14, I16), most of the contaminated water samples taken during wet months came from stations near the Tijuana River mouth (Appendix A.2). The July sewage spill into the Tijuana River that impacted the shore stations was not detected in the kelp station samples.

Contaminated water samples considered indicative of the wastewater plume (i.e., total coliforms ≥1000 CFU/100 mL and F:T ratios ≥0.1) were detected most frequently at stations along the 28-m depth contour, which is the depth of the SBOO discharge (**Figure 3.6A**). Nineteen of the 39 samples identified as representing contaminated water occurred along or near the 28-m contour: 15 at the stations nearest the outfall (I12, I14, I16), one at northern station I30, and 3 at southern stations I3 and I9. Only 2 samples were collected farther offshore than the 28-m depth contour (I20, I21). The rest of the samples indicative of contaminated water came from stations along the 9–19 m depth contours.

There was limited evidence that the wastewater plume reached surface waters in 2006, as only 7 of the 39 contaminated water samples occurred in surface waters (2 m) (Figure 3.6B). These samples were collected in January, March, April, June, and October (Appendix A.2). The January sample was collected from outfall station I12 when there was no thermocline. The March sample was collected

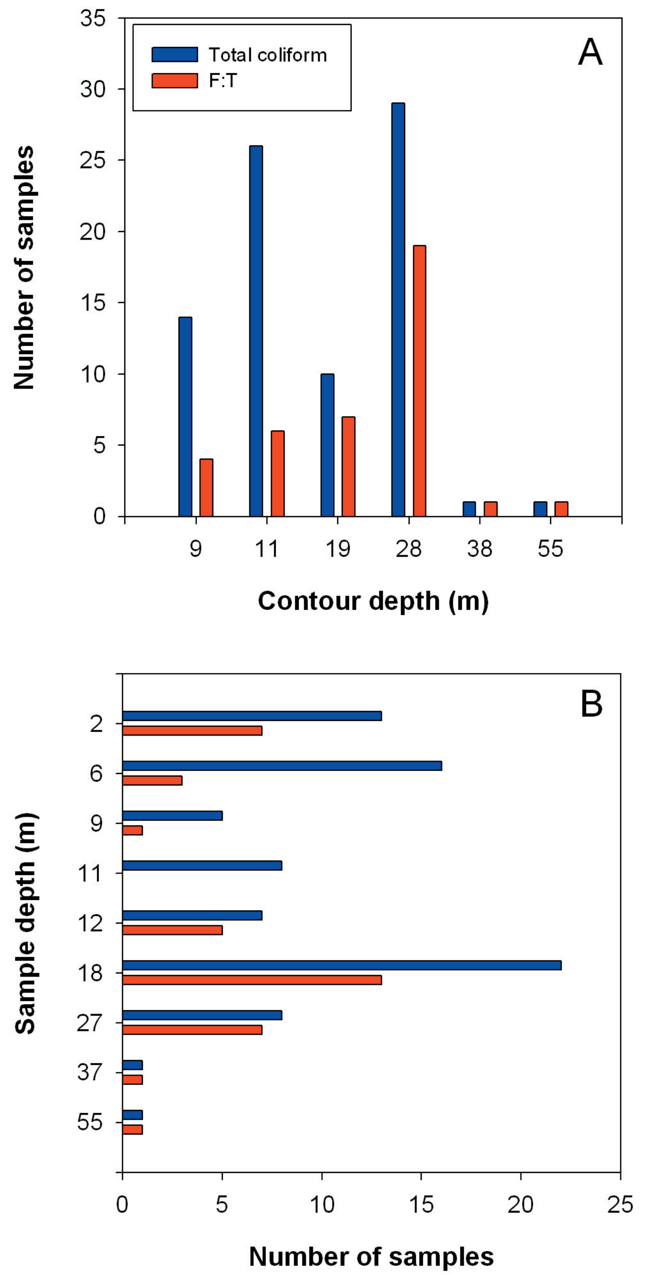


Figure 3.6
SBOO monthly offshore water quality samples with high bacterial densities depicted by (A) contour and (B) depth in 2006. Total coliform=number of samples with total coliform densities ≥1000 CFU/100 mL (n=81); F:T=number of samples with total coliform densities ≥1000 CFU/100 mL and fecal to total coliform ratio (F:T) ≥0.1 (n=38).

at station I40 after the Tijuana River began flowing following later February rainfall. The April samples occurred at stations I19 and I40 and may have been affected by the Tijuana River and Los Buenos Creek, Mexico turbidity plumes. These plumes were probably the result of 0.5 inches of rain from

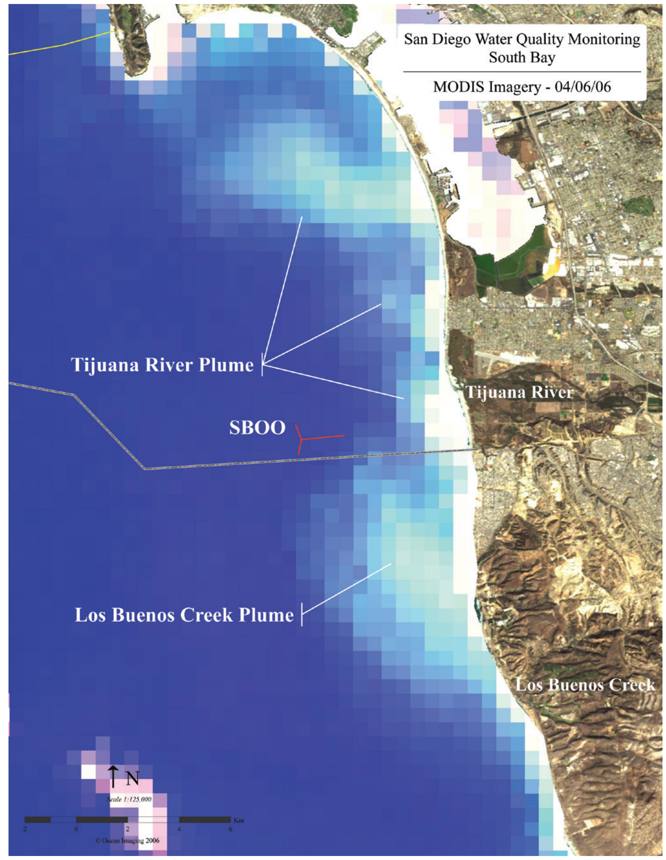


Figure 3.7
MODIS satellite image showing the San Diego water quality monitoring region on April 6, 2006. White pixels represent areas obscured by cloud cover.

the previous 2 days and were visible in MODIS imagery taken on April 6 (**Figure 3.7**). The cause of the contaminated samples at inshore stations I5 and I11 in June and I5 in October was not apparent.

Compliance with California Ocean Plan Standards

Compliance with COP bacterial standards in 2006 for shore and kelp bed stations in the U.S. is summarized in **Tables 3.2** and **3.3**. Overall, compliance was higher in 2006 than in 2005, which was probably related to the lower rainfall during the past year (City of San Diego 2006). For example, compliance with the 30-day total coliform standard at the shore stations ranged from 49 to 95% in 2006 versus 36 to 81% in 2005. In addition, the number of days that samples at the shore stations were out of compliance with the 10,000 total coliform standard decreased from 41 in 2005 to 28 in 2006. The frequency of compliance

Table 3.2

Summary of compliance with 2001 California Ocean Plan water contact standards for SBOO shore and kelp bed stations during 2006. Values reflect the number of days that each station exceeded the 30-day and 10,000 total coliform standards (see Box 3.1). Shore stations are listed north to south in order from left to right.

30-day Total coliform standard					**Shore stations**					**Kelp stations**		
Month	**# days**	**S9**	**S8**	**S12**	**S6**	**S11**	**S5**	**S10**	**S4**	**I25**	**I26**	**I39**
January	31	0	20	20	0	0	0	28	28	0	0	0
February	28	0	0	0	1	7	7	1	1	0	0	0
March	31	2	0	26	31	31	31	25	25	0	0	0
April	30	18	0	30	30	30	30	30	30	0	0	0
May	31	0	0	10	8	31	31	31	24	0	0	0
June	30	0	0	0	0	1	28	26	0	0	0	0
July	31	0	0	10	0	0	13	5	5	0	0	0
August	31	0	0	9	0	0	16	14	14	0	0	0
September	30	0	0	0	0	0	0	0	0	0	0	0
October	31	0	0	0	14	14	14	0	0	0	0	0
November	30	0	0	0	15	15	15	0	0	0	0	0
December	31	0	0	0	0	0	0	19	19	0	0	0
Percent compliance		**95%**	**95%**	**71%**	**73%**	**65%**	**49%**	**51%**	**60%**	**100%**	**100%**	**100%**
10,000 Total coliform standard												
January	31	0	0	0	0	0	0	1	1	0	0	0
February	28	0	0	0	0	1	2	0	0	0	0	0
March	31	0	0	0	1	0	3	1	1	0	0	0
April	30	0	0	1	1	2	1	1	2	0	0	0
May	31	0	0	0	0	1	3	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0	0	0	0
October	31	0	0	0	1	1	1	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	1	1	0	0	0
Total		**0**	**0**	**1**	**3**	**5**	**10**	**4**	**5**	**0**	**0**	**0**

with standards based on running means (i.e., the 30-day total, 60-day fecal, and geometric mean standards) was lowest from March through June, when cumulative rainfall was greatest. In contrast, the 3 kelp stations were 100% compliant with all COP standards.

As in the previous years, rainfall caused low compliance rates for the shore stations closest to the Tijuana River. Only the 2 northernmost shore stations (S8 and S9) were compliant with the 30-day total and 60-day fecal coliform standards over 90% of the time. By contrast, percent compliance at the more southern stations ranged from 33 to 73% for these same standards. The proximity of these shore stations to the Tijuana River may explain the frequency with which they were out of compliance. Lower runoff volumes and the absence of frequent and persistent northward currents probably attributed to the increased compliance at stations north of the Tijuana River relative to previous years (City of San Diego 2006, Ocean Imaging 2006a).

Table 3.3

Summary of compliance with 2001 California Ocean Plan water contact standards for SBOO shore and kelp bed stations during 2006. Values reflect the number of days that each station exceeded the 60-day fecal coliform and geometric mean standards (see Box 3.1). Shore stations are listed north to south in order from left to right.

60-day Fecal coliform standard		Shore stations								Kelp stations		
Month	**# days**	**S9**	**S8**	**S12**	**S6**	**S11**	**S5**	**S10**	**S4**	**I25**	**I26**	**I39**
January	31	0	0	0	0	0	0	12	12	0	0	0
February	28	0	0	1	4	4	8	13	13	0	0	0
March	31	0	0	31	16	9	31	29	29	0	0	0
April	30	0	0	30	30	30	30	30	30	0	0	0
May	31	0	0	31	31	31	31	31	31	0	0	0
June	30	0	0	18	14	30	30	30	24	0	0	0
July	31	0	7	24	19	19	31	23	7	0	0	0
August	31	0	12	31	12	12	12	0	31	0	0	0
September	30	0	5	15	5	5	5	0	22	0	0	0
October	31	0	0	7	15	15	15	7	0	0	0	0
November	30	0	0	12	30	30	30	12	0	0	0	0
December	31	0	0	6	16	16	23	26	20	0	0	0
Percent compliance		**100%**	**93%**	**44%**	**47%**	**45%**	**33%**	**42%**	**40%**	**100%**	**100%**	**100%**
Geometric mean standard												
January	31	0	0	0	0	0	0	0	0	0	0	0
February	28	0	0	0	0	0	0	0	0	0	0	0
March	31	0	0	0	0	0	31	11	3	0	0	0
April	30	0	0	5	24	26	30	5	10	0	0	0
May	31	0	0	0	0	14	31	10	11	0	0	0
June	30	0	0	0	0	0	22	5	0	0	0	0
July	31	0	0	0	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	0	0	0	0	0	0
Percent compliance		**100%**	**100%**	**99%**	**93%**	**89%**	**69%**	**92%**	**93%**	**100%**	**100%**	**100%**

Bacterial Patterns Compared to Other Wastewater Indicators

Results from the oil and grease and total suspended solids (TSS) sampling suggest that both have limited utility as indicators of the waste field in 2006. Oil and grease concentrations were mostly below the detection limit (<1.4 mg/L) in 2006 (**Table 3.4**). The only exception was an oil and grease value of 2.23 mg/L of an uncertain cause that occurred in May at station I30, located over 5 km north of the SBOO. Data from bacteria samples suggest that the plume was traveling southward at the time since concentrations of indicator bacteria were low (<2 CFU/100 mL) in the samples from I30 but high in samples at depths of 6 m and below at stations I10, I11, and I12. Monthly mean TSS concentrations ranged from 5.2 to 10.2 mg/L (Table 3.4). Individual values varied considerably, ranging between <1.6 and 74.3 mg/L, and were not significantly correlated with total or fecal coliform concentrations or F:T (**Table 3.5**). Of the 183 TSS samples with elevated concentrations (≥10.0 mg/L), only 81 (44%) corresponded to samples with total coliform densities ≥1000 CFU/100 mL, and only 38 (21%) of these had F:T ratios ≥0.1.

Table 3.4

Means (±SE) for total suspended solids (TSS; 3 depths) and detected oil and grease (O&G; 2 m depth) for each SBOO monthly water quality station during 2006. Ranges are given in parentheses; n=84. nd= not detected. The minimum levels of detection are 1.4 mg/L. (O&G) and 1.6 mg/L (TSS).

Month	O&G mg/L	TSS mg/L
January	nd	6.4±0.8 (<1.6–52.0)
February	nd	6.5±0.5 (2.5–32.7)
March	nd	6.6±0.4 (2.0–18.1)
April	nd	7.5±1.0 (2.0–74.3)
May	2.23	6.1±0.5 (1.9–23.3)
June	nd	6.4±0.5 (2.2–25.5)
July	nd	9.2±0.4 (4.6–27.8)
August	nd	10.2±0.7 (<1.6–30.5)
September	nd	7.9±0.4 (2.8–20.7)
October	nd	5.2±0.2 (1.7–13.2)
November	nd	7.6±0.3 (2.0–14.6)
December	nd	7.4±0.4 (3.0–32.9)

Table 3.5

Spearman rank correlation results for total suspended solids from SBOO monthly offshore stations from 1995–2006.

Correlation	Period	r_s	n	P
Total coliform	2006	-0.019	1006	0.54
Fecal coliform	2006	<-0.001	1007	0.99
Fecal:total coliform	2006	0.006	1006	0.86
Total coliform	95–06	0.019	11,359	<0.001
Fecal coliform	95–06	0.153	11,373	<0.001
Fecal:total coliform	95–06	-0.173	11,358	<0.001

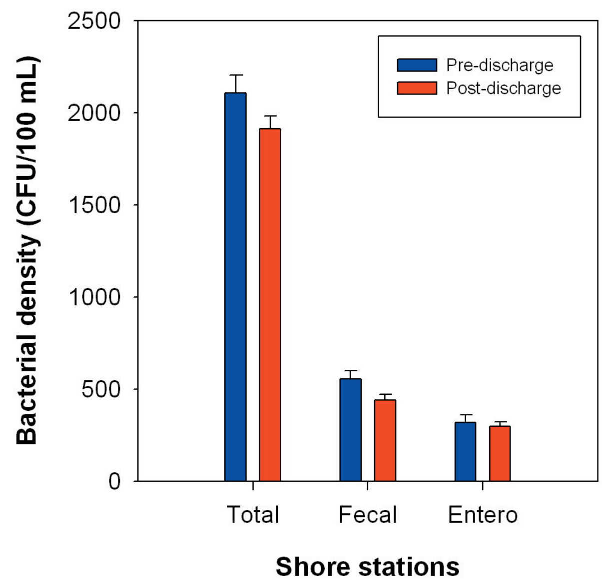


Figure 3.8

Mean bacterial densities (mean±SE) for SBOO shore stations from 1995–2006. The pre-discharge period is from October 2, 1995 to January 12, 1999 while post-discharge is from January 13, 1999 to December 31, 2006. Sample size=Pre/Post. Total=total coliform (n=2471/4445), Fecal=fecal coliform (n=2515/4455), Entero=enterococcus (n=1388/4343).

Historical Analyses

Mean total and fecal coliform densities along the shore have been lower since discharge began in January 1999 **(Figure 3.8).** The differences in the transformed data were slight, but significant (**Table 3.6**), some of which was caused by differences in bacterial densities at specific stations. For example, the largest decline in mean fecal coliform densities occurred at station S5 (**Figure 3.9**), which is likely related to diverting discharge that flowed into the Tijuana River to the SBOO.

Kelp station mean total coliform densities declined during the post-discharge period, while fecal coliform and enterococcus densities increased slightly (**Figure 3.10A**). Despite a lot of variation during the pre-discharge period, the difference in mean total coliform densities was significantly lower during the post-discharge period (Table 3.6).

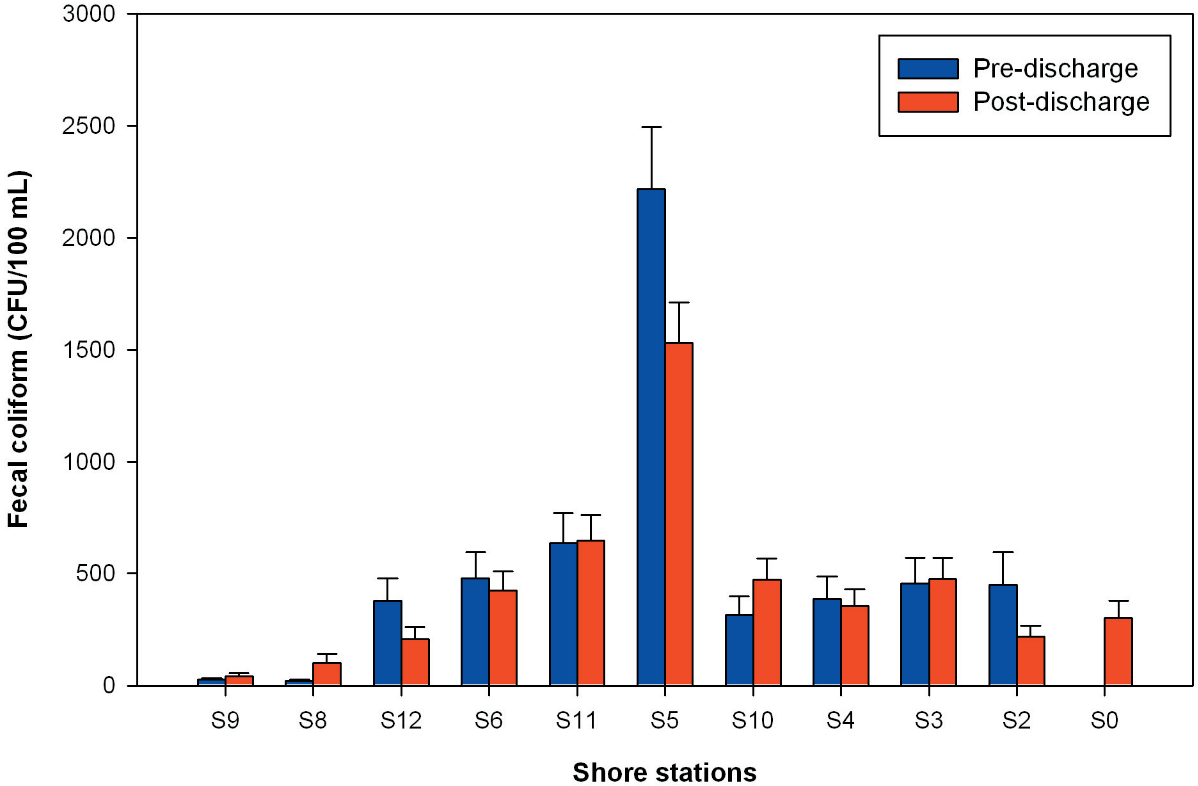


Figure 3.9

Mean fecal coliform densities (mean±SE) for SBOO shore stations from 1995–2006. The pre-discharge period is from October 2, 1995 to January 12, 1999 (n=147–297) while post-discharge is from January 13, 1999 to December 31, 2006 (n=226–430). Stations are arranged from north to south on the x-axis. Stations S5, S6, and S11 are all within 1 km of the Tijuana River. Sampling for stations S10–S12 started in October 1996 and station S0 in August 2002.

The pre- and post-discharge differences in the other bacterial indicators were not significant. Post-discharge fecal coliform densities show the greatest increase from the 12-m depth samples, all of which were collected from station I39 (Figure 3.10B). However, all of the mean fecal coliform densities for each depth and period were low.

In contrast to the shore stations, the mean bacteriological densities from monthly offshore stations increased during the post-discharge period (**Figure 3.11**, Table 3.6). The highest pre-discharge fecal coliform densities were detected at along the 9 and 11-m depth contours (**Figure 3.12A**) and were most likely caused by stormwater and river discharge from the Tijuana River. During the post-discharge period, mean fecal coliform densities increased dramatically along the 28-m depth contour, the depth at which treated effluent is discharged from the SBOO. The highest mean fecal coliform densities came from the 18 m depth samples, mostly from stations I12, I14, and I16 near the SBOO diffuser wye (Figure 3.12B).

The percent of oil and grease detected in offshore station water samples increased during the post-discharge period (**Figure 3.13**). However, the difference in measured oil and grease concentrations was not significant (independent sample t-test: t=0.65; df=68; P=0.516). Oil and grease were detected in only 0.35% of the pre-discharge samples versus 2.49% of the post-discharge samples. Oil and grease were never detected in any samples from the 9-m, 38-m, and 55-m contours during the pre-discharge period, whereas during the post-discharge

Table 3.6

Independent sample t-test results for pre-discharge versus post-discharge periods from SBOO shore (Shore), biweekly kelp (Kelp), and monthly offshore (Offshore) stations. Data are log(x+1) transformed. The pre-discharge period is from October 2, 1995 to January 12, 1999 while post-discharge is from January 13, 1999 to December 31, 2006.

	Variable	t	df	P
Shore	Total coliform	-3.85	6914	<0.001
	Fecal coliform	-6.47	5002	<0.001
	Enterococcus	-3.99	2255	<0.001
Kelp	Total coliform	3.12	4579	0.002
	Fecal coliform	1.89	412	0.060
	Enterococcus	-0.01	4625	0.989
Offshore	Total coliform	13.63	7554	<0.001
	Fecal coliform	14.81	9357	<0.001
	Enterococcus	4.02	7314	<0.001

period, they were distributed across all contours, with the highest detection rate occurring at the 38-m contour.

Measured levels of TSS in offshore station water samples also increased during the post-discharge period. While the difference in mean levels was significant (independent sample t-test: t=15.60; df=6875; P<0.001), the actual difference was small (mean±SE: pre-discharge=5.04±0.07 mg/L; post-discharge=6.13±0.05 mg/L). Mean levels of TSS increased along all sampled contours during the post-discharge period (**Figure 3.14A**). In addition, post-discharge mean levels of TSS were higher from most sample depths (Figure 3.14B). The 1995–2006 data showed a significant correlation between TSS and total and fecal coliforms, including F:T, in the offshore station water samples (Table 3.5). While these relationships are significant, little of the variation is explained. This is shown in **Figure 3.15**, where water samples contain a range of TSS values that coincide with elevated total fecal coliforms.

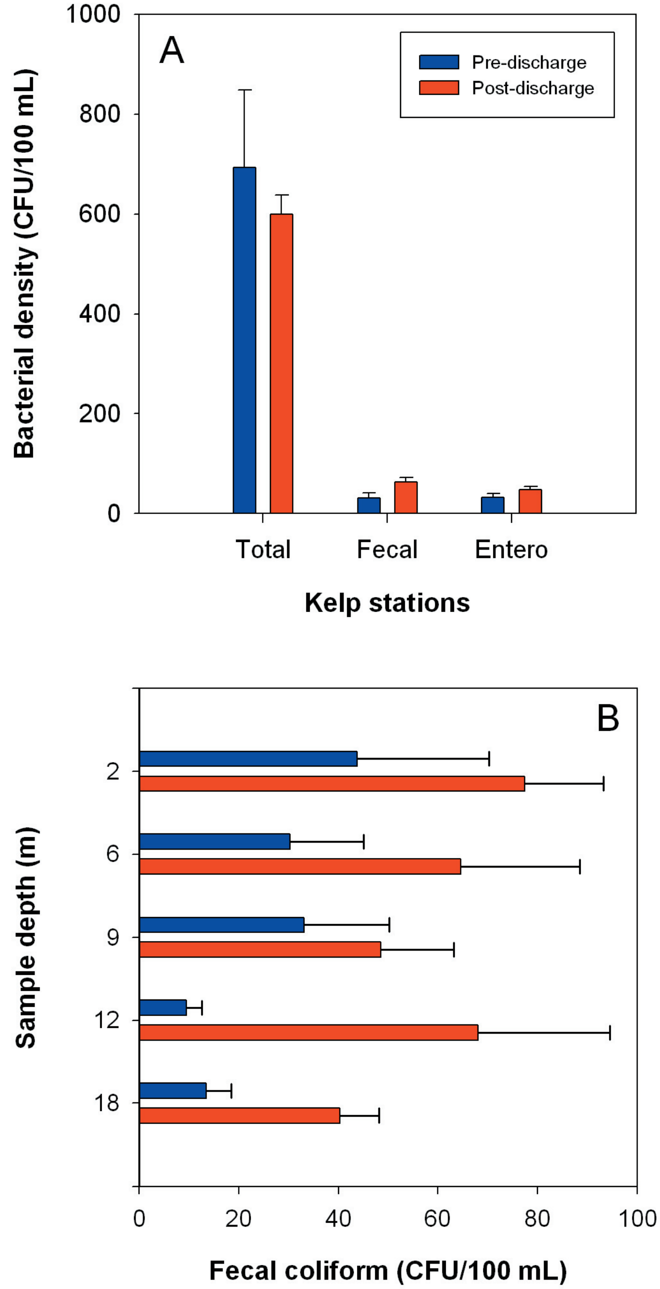


Figure 3.10

SBOO kelp station mean bacterial densities (mean±SE) collected by (A) period and (B) depth from 1995–2006. The pre-discharge period is from October 2, 1995 to January 12, 1999 while post-discharge is from January 13, 1999 to December 31, 2006. Sample size=Pre/Post. Total=total coliform (n=342/4239), Fecal=fecal coliform (n=342/4285), Entero=enterococcus (n=342/4285).

SUMMARY AND CONCLUSIONS

Bacterial concentrations in shore station samples that exceeded COP standards in 2006 appear to have been caused by contamination from either river discharge or from runoff during and after storm events. Bacterial concentration and visible satellite imagery data indicate that flows from the Tijuana River, Los Buenos Creek, and non-point source

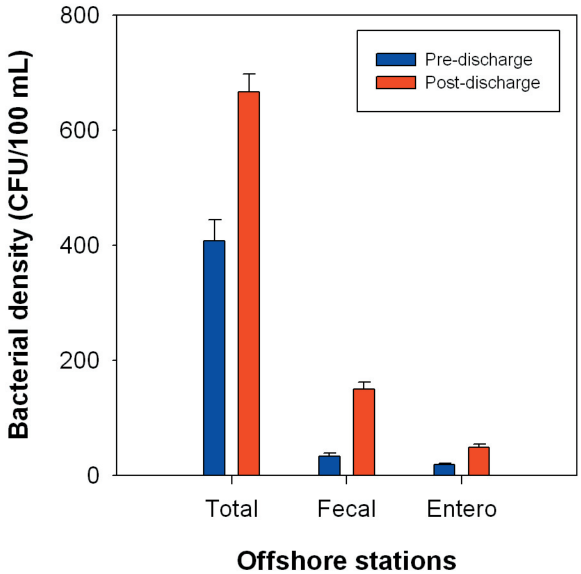


Figure 3.11

Mean bacterial densities (mean±SE) for SBOO monthly offshore stations from 1995–2006. The pre-discharge period is from October 2, 1995 to January 12, 1999 while post-discharge is from January 13, 1999 to December 31, 2006. Sample size=Pre/Post. Total=total coliform (n=3421/7962), Fecal=fecal coliform (n=3428/7969), Entero=enterococcus (n=3428/7970).

stormwater runoff are more likely than wastewater discharge to impact water quality along and near the shore.

Data from the bacterial analyses indicate that the wastewater plume from the SBOO rarely reached surface waters in 2006. Thermal stratification that began in March/April likely prevented the wastewater plume from surfacing through most of the year. Most elevated bacterial counts evident of contamination near the surface in January, March, April, June, and October occurred during periods of rainfall or when turbidity plumes from the Tijuana River or Los Buenos Creek reached the affected stations. Results highly indicative of wastewater reaching the surface occurred only in January near the outfall diffusers (station I12). The majority of the subsurface (>2 m depth) monthly water quality samples indicative of the wastewater plume occurred at depths of 18 m and below. Stations near the outfall had the highest incidences of samples indicative of wastewater, which were collected throughout the year.

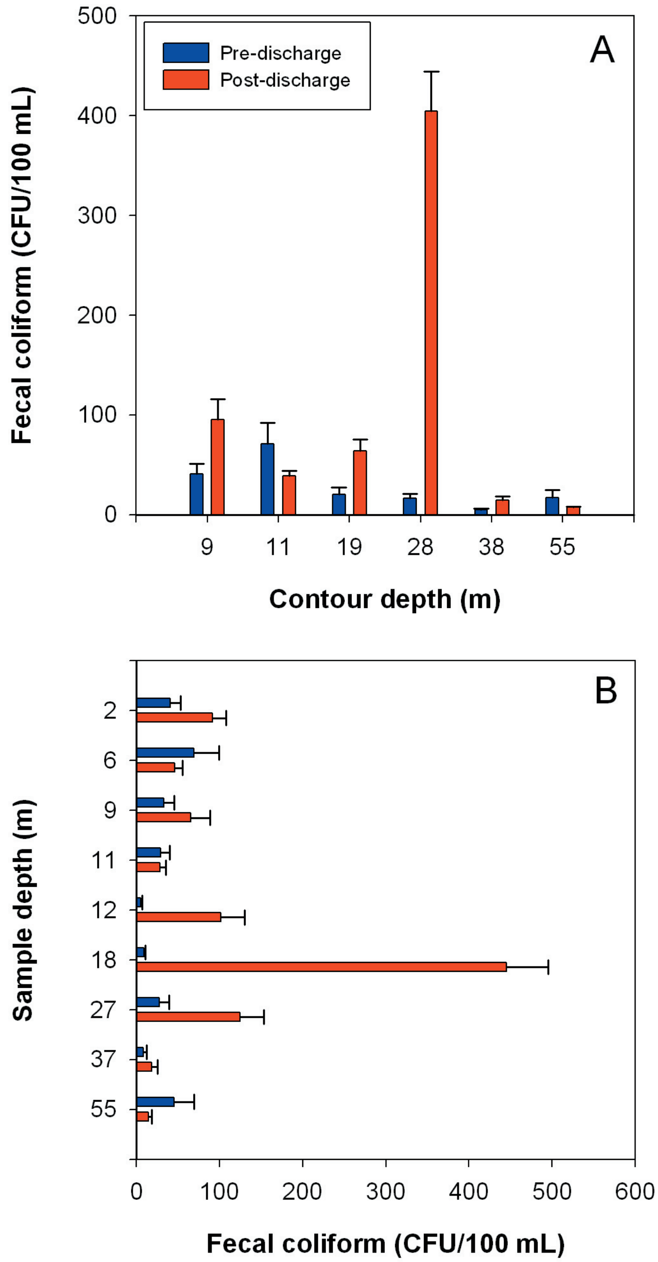


Figure 3.12

SBOO monthly offshore mean fecal coliform densities (mean±SE) collected by (A) transect and (B) depth from 1995–2006. The pre-discharge period is from October 2, 1995 to January 12, 1999 (n=3428) while post-discharge is from January 13, 1999 to December 31, 2006 (n=7969).

Rain and flows from the Tijuana River and Los Buenos Creek appear to be the primary sources of the nearshore bacteriological contamination. These conditions had the largest impact on water quality in the South Bay region during 2006. Although elevated bacterial densities were detected at the 9 to 19-m depth contour stations and shore stations

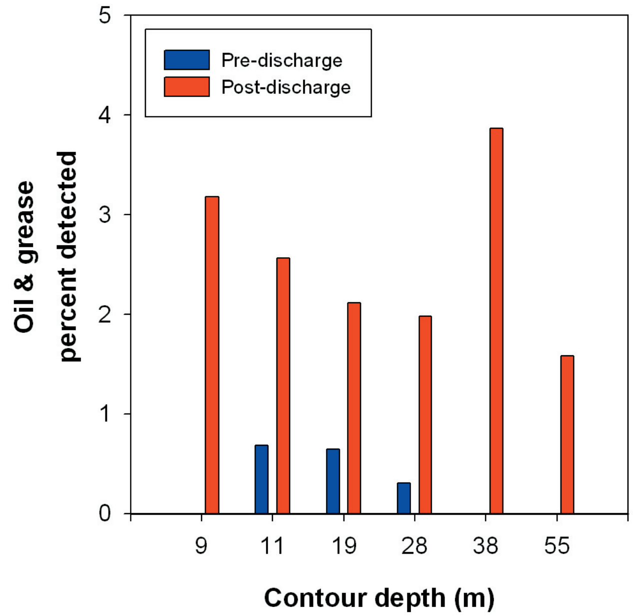
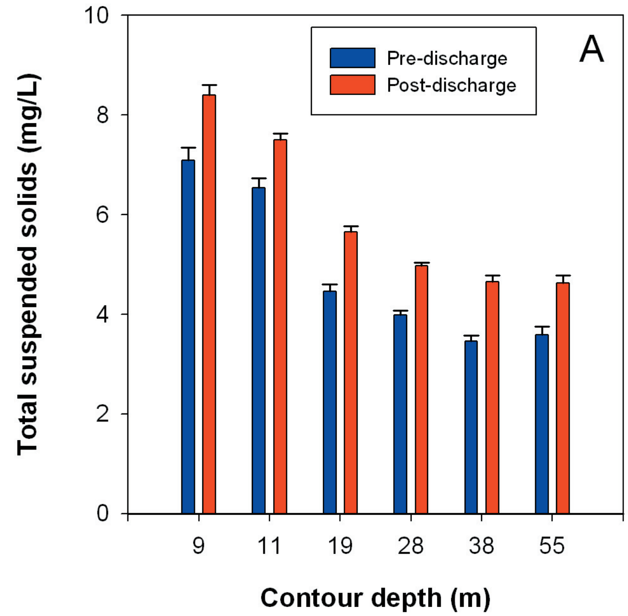


Figure 3.13
Percent of water samples where oil and grease were detected for SBOO monthly offshore stations from 1995–2006. The pre-discharge period is from October 2, 1995 to January 12, 1999 (n=1143) while post-discharge is from January 13, 1999 to December 31, 2006 (n=2653). The O&G detection level changed from 0.2 to 1.4 mg/L in January 2003.

throughout the year, these data do not indicate a shoreward transport of the SBOO discharge plume.

A historical analysis indicated that mean coliform bacteriological densities at shore stations were slightly lower during the post-discharge period. While the mean total coliform density from the kelp stations was lower during the post-discharge period, all mean bacteriological densities at kelp stations were low during both periods. In contrast, offshore station mean bacteriological densities increased during the post-discharge period and were highest at the stations nearest the SBOO diffusers. Measured levels of oil and grease were detected more frequently and total suspended solids were slightly higher during the post-discharge period. While total suspended solids are not a consistent indicator of the waste field, there is a significant relationship which explains little of the variability between total coliforms and total suspended solids for the period from 1995–2006.



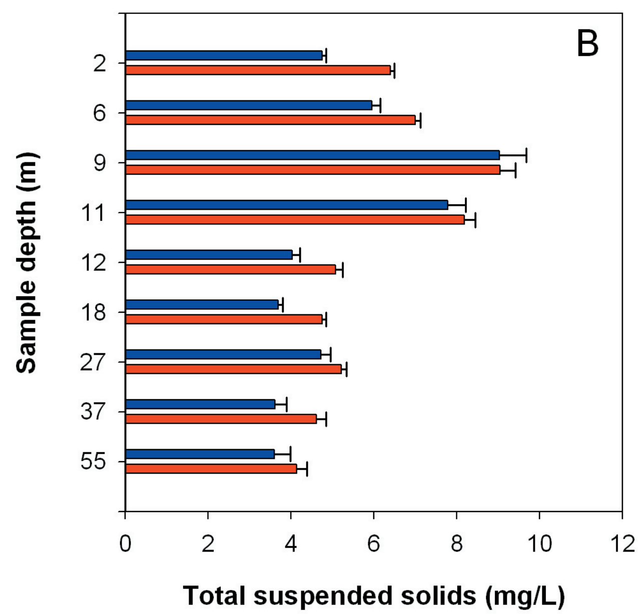


Figure 3.14
SBOO monthly offshore mean total suspended solids (mean±SE) collected by (A) transect and (B) depth from 1995–2006. The pre-discharge period is from October 2, 1995 to January 12, 1999 (n=3413) while post-discharge is from January 13, 1999 to December 31, 2006 (n=7975).

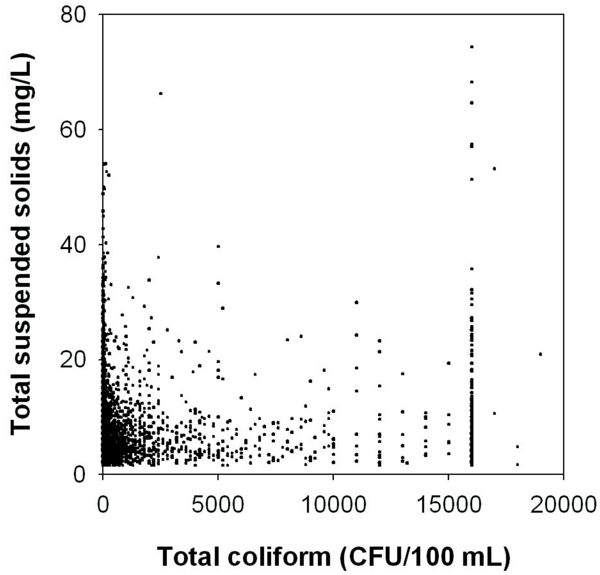


Figure 3.15
SBOO monthly offshore total suspended solids and total coliform densities from 1995–2006 (n=11,359).

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